Closed Loop Control on Battery Power Limits Based on Voltage

Background

Both pure and hybrid electric vehicles, as shown in Figure 1 and Figure 2, use battery and electric motor in their powertrain systems. The battery provides energy/power to the electric motor as the gasoline to the engine. However, unlike gasoline that contains the same amount of energy/power regardless of the amount of gasoline in the gas tank, the energy/power availability varies depending upon the battery conditions (e.g. battery state of charge and temperature). Therefore, the commands to the electric motor will be limited by the battery power availability, as shown in Figure 1 and Figure 2. The accuracy of these battery limits are essential to maintain the battery voltage within a certain range to ensure the powertrain system working properly, and more importantly to prevent electric motor and its controller from shutdown due to under or over battery voltage.

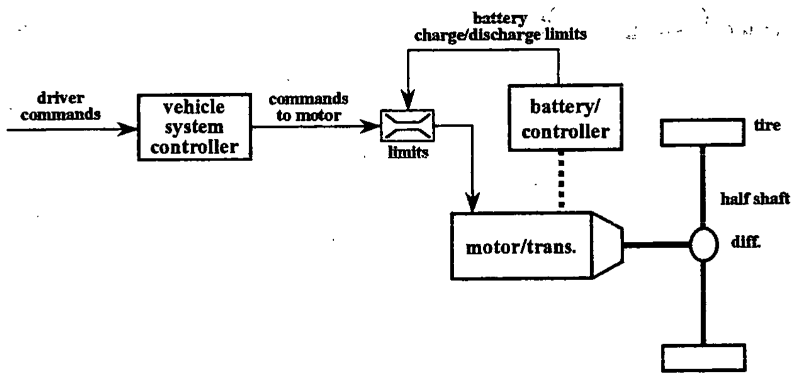

Figure 1 Electric Vehicle Powertrain System

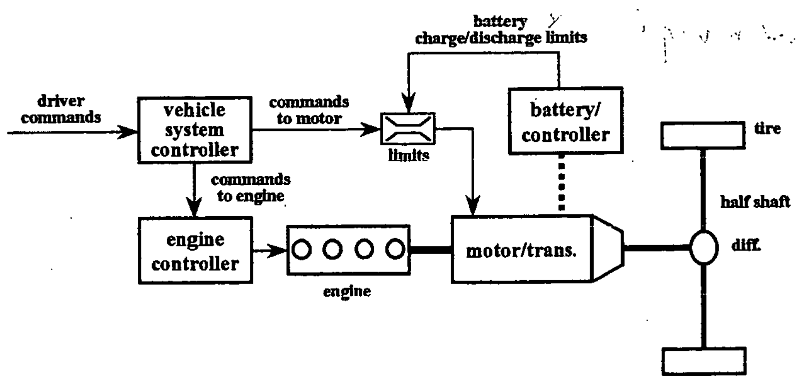

Figure 2 Hybrid Electric Vehicle Powertrain System

Problem Description

As mentioned above, the accuracy of the battery limits plays an important role in ensuring the battery voltage within a certain range. The inaccuracy of the limits can potentially cause the unnecessary vehicle quit on the road (QOR). Given the complexity of electro-chemistry in the battery, the battery controller could sometimes inaccurately estimate the battery's discharge and

charge power limits. The inaccurate estimation will cause the battery voltage out of the proper range, which in turn could result in QOR.

Invention:

This invention is a closed loop control system to modify the battery limits from the battery controller when necessary. This control system compensates the inaccuracy of the battery limits estimation by the battery controller, so the unnecessary QOR can be prevented. For given battery voltage set points (upper and lower bounds), the control system uses actual battery voltage as a feedback signal, and creates a modification to the battery power limits from the battery controller if the actual the battery voltage is out of bounds. Clearly, if the battery voltage is within the bounds, this control system has no change to the battery power limits from the battery controller. Figure 3 shows the control system configuration in the vehicle level. Figure 4 details the battery power limits closed loop control system.

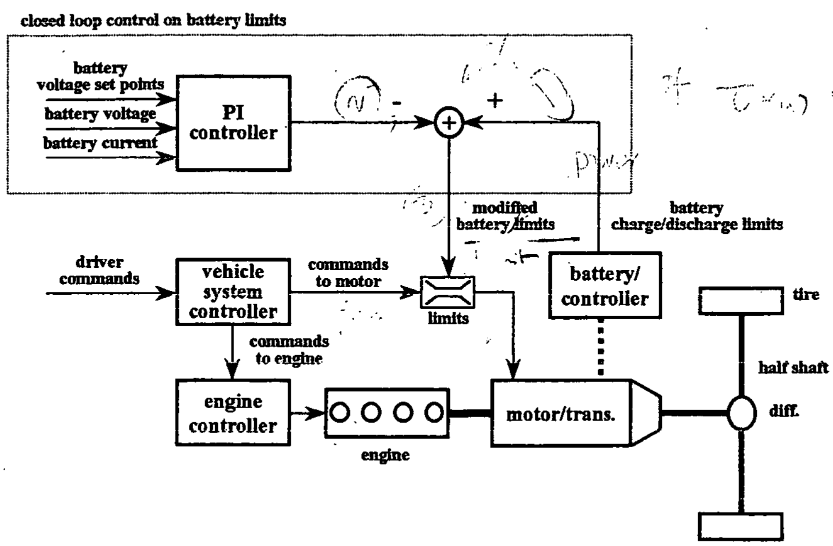

Figure 3 Closed Loop Control System on Battery Limits

It is noted that the battery limits are the battery discharge and charge power limits, and that the sign convention for the battery power flows (discharge and charge) is as follows: discharging is positive and charging is negative. Therefore, the battery discharge power limit is a positive value while the battery charge power limit is a negative value; positive battery current means discharging, and negative battery current means charging.

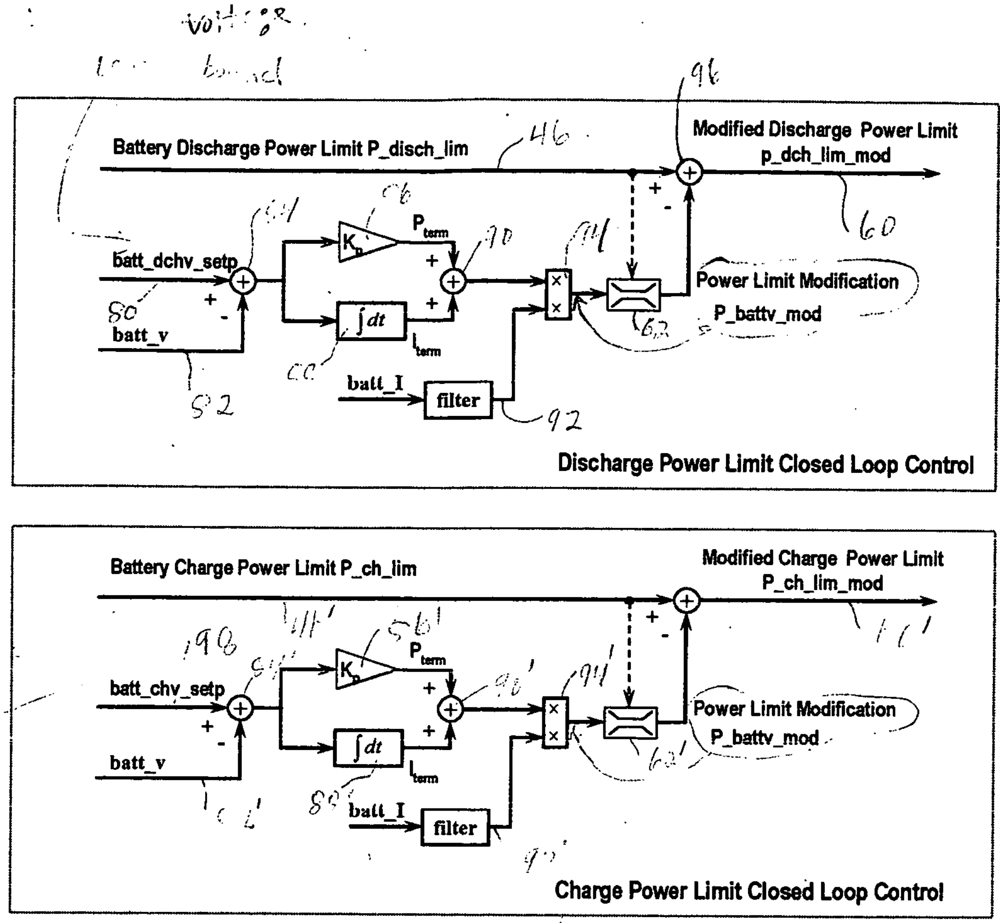

Figure 4 Battery Limits Closed Loop Control System

Invention Flowchart Description

Figure 5 and Figure 6 are the flowcharts of closed loop control of battery discharge and charge power limits respectively.

The closed loop control of battery discharge power limit works, as shown in Figure 5, in the following manner:

First, the program reads the battery discharge power limit (**p_dch_lim**), battery discharge voltage set point (**batt_dchv_setp**), battery voltage (**batt_v**) and battery current (**batt_I**), and sets the battery limit modification (**p_battv_mod**) and **I_term** to zero, and index (run number) to 1;

Secondly, filter the battery current using low pass filter (the filter time constant can be varied depending on the noise level of the signal) and clip the filtered battery current to greater than or equal to zero; then calculate the voltage error (**batt_dchv_err**).

Third, calculate the proportional and integral term of the PI controller:

Proportional Term

- Clip the error signal to positive values so that the proportional term only modifies the battery discharge limit if the voltage is below the set-point.

- Multiply the clipped error signal by the proportional gain (**K_p**). This is the proportional term (**P_term**).

Integral Term

- Check if battery power limit modification (**p_battv_mod**) greater than battery discharge power limit (**p_dch_lim**). If so, do not update the **I_term** . This will freeze the integrator and prevent the integrator from winding up. Otherwise, update the **I_term** with the current voltage error (equivalent to integration).
- Reset the **I_term(N)** to zero if **I_term(N)** goes negative.
- Reset the previous **I_term (N-1)** to the present **I_term** out put (**I_term(N)**)

Power Limit Modification p_battv_mod (sum of proportional and integral terms)

- Add the proportional and integral terms and multiply the sum by filtered battery current. The battery current is low pass filtered with a calibrateable filter time constant. This will allow the same PI controller, with the same PI gains to be used when the internal battery resistance is higher (example: very low battery temperatures.)

Finally, calculate the modified discharge power limit by subtracting the power limit modification **p_battv_mod** from the discharge power limit **p_dch_lim**.

The closed loop control of battery charge power limit works, as shown in Figure 6, in a similar manner as above.

Invention Advantage

As mentioned earlier, the advantage of this invention is to compensate the inaccuracy of the battery limits estimated by the battery controller, to prevent the vehicle from QOR. The invention can be applied to both electric vehicles and hybrid electric vehicles.

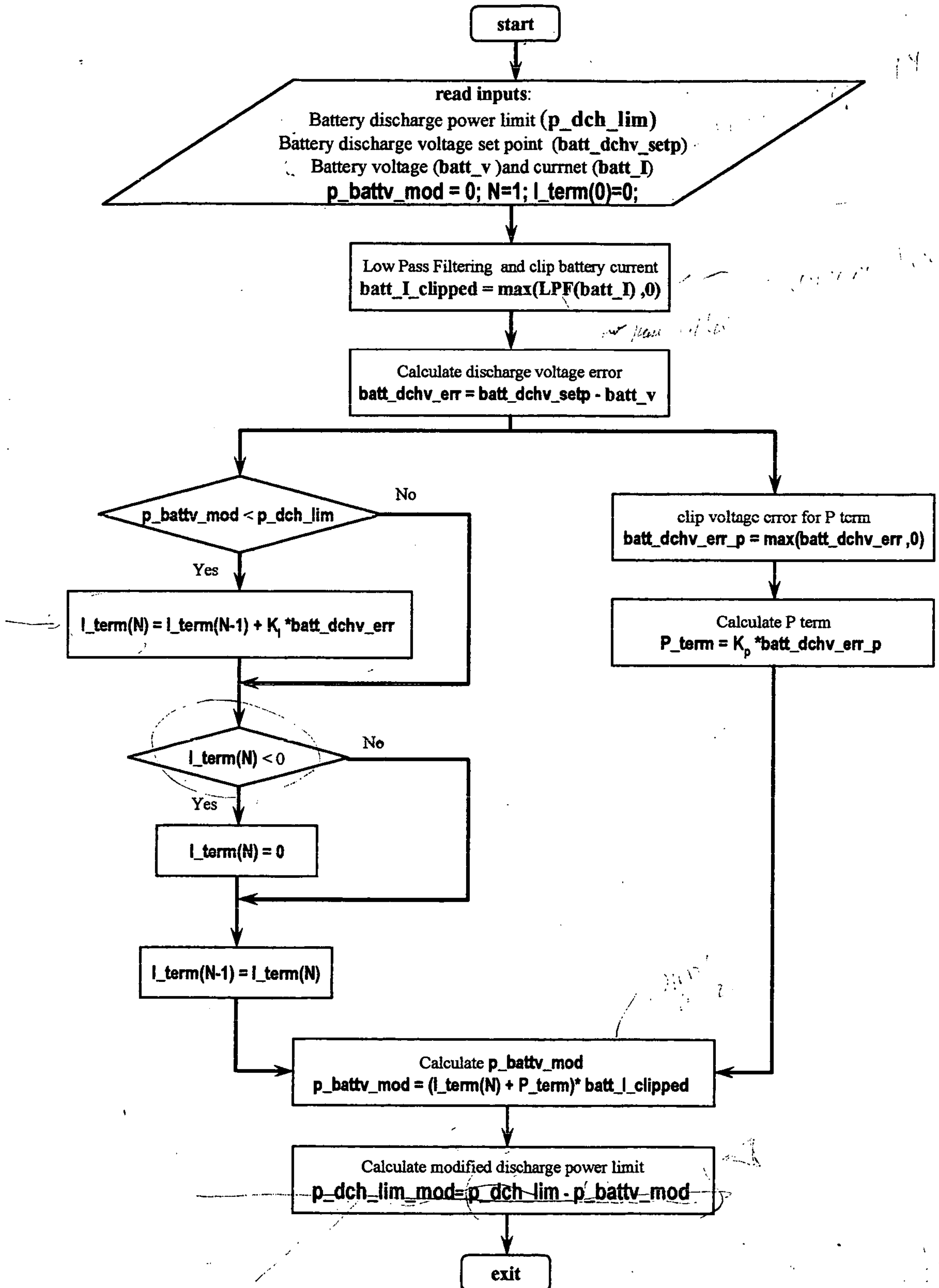

Figure 5 Flowchart of Discharge Power Limit Closed Loop Control

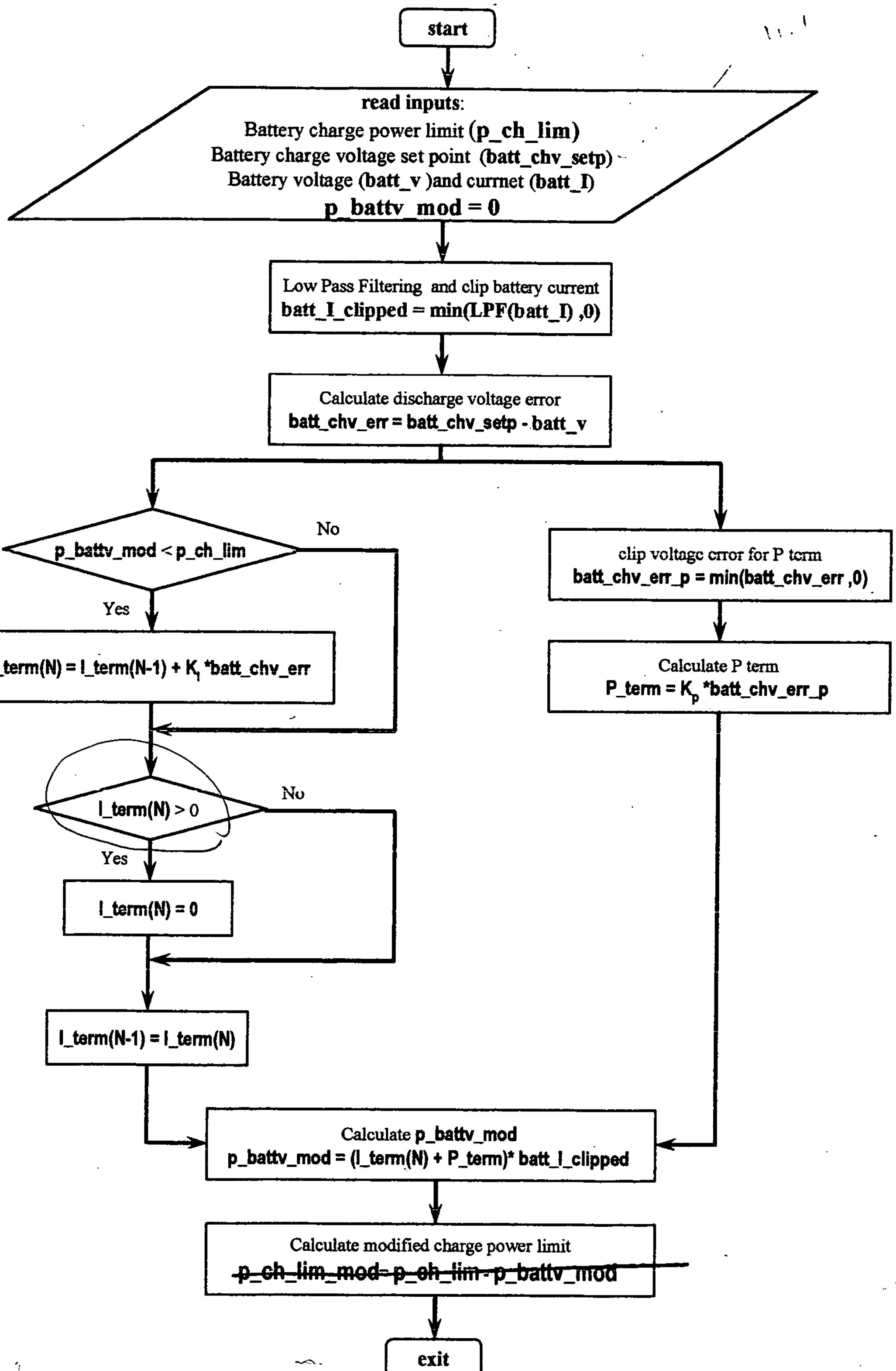

Figure 6 Flowchart of Charge Power Limit Closed Loop Control